Photon Detection R&D for ν LArTPCs

M. Toups
MIT

Workshop on the Intermediate Neutrino Program
Feb. 5, 2015

Outline

- LAr scintillation light

- LAr light detection motivation
  - Key R&D goals

- R&D related to LAr scintillation

- SiPM R&D opportunities

LAr Scintillation light

- LAr is a bright scintillator: O(10,000) γ/MeV

- LAr scintillates in the VUV at 128 nm

- LAr is very transparent to its own light
  - Rayleigh scattering length: λ≈90 cm

- LAr light divided between two components
  - Fast component: τ≈6 ns
  - Slow component with τ≈1.5 us

- LAr scintillation light and charge anti-correlation
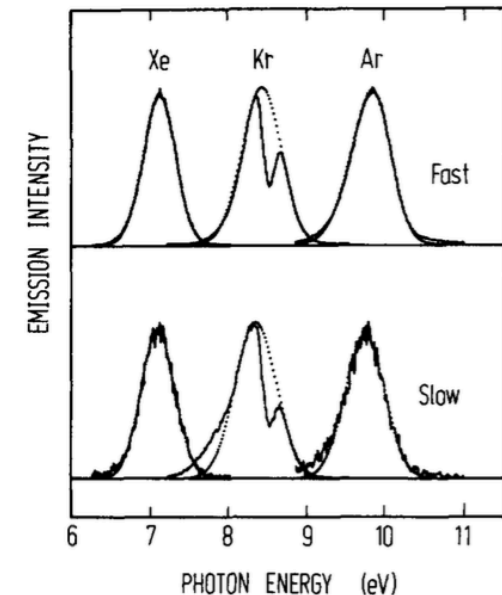
E Morikawa et al.., J Chem Phys vol 91 (1989) 1469

LAr Scintillation light

- LAr is a bright scintillator: O(10,000) γ/MeV

- LAr scintillates in the VUV at 128 nm
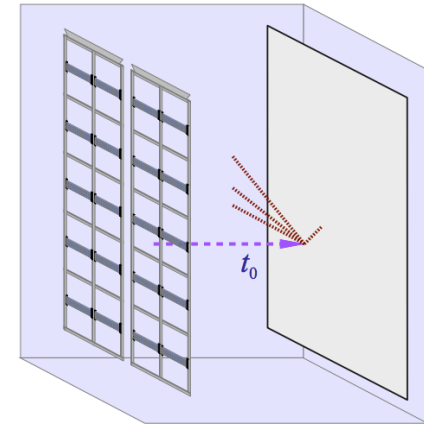
- LAr is very transparent to its own light
  - Rayleigh scattering length: λ≈90 cm

- LAr light divided between two components
  - Fast component: τ≈6 ns
  - Slow component with τ≈1.5 us

- LAr scintillation light and charge anti-correlation

Standard SiPMs/PMTs not sensitive at this wavelength, so use wavelength shifters

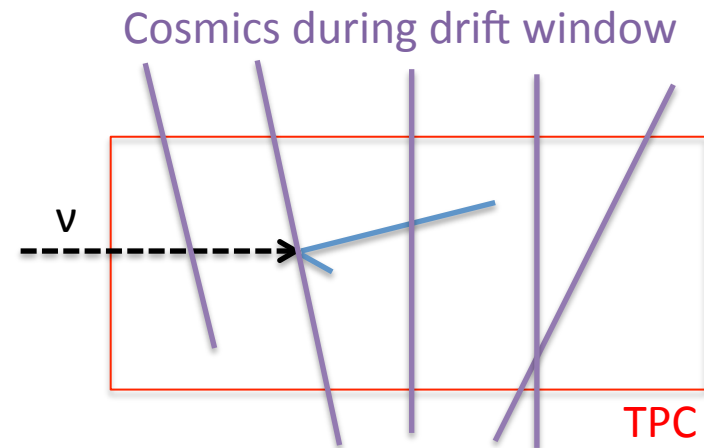Tetraphenyl butadiene (TPB) evaporative coating
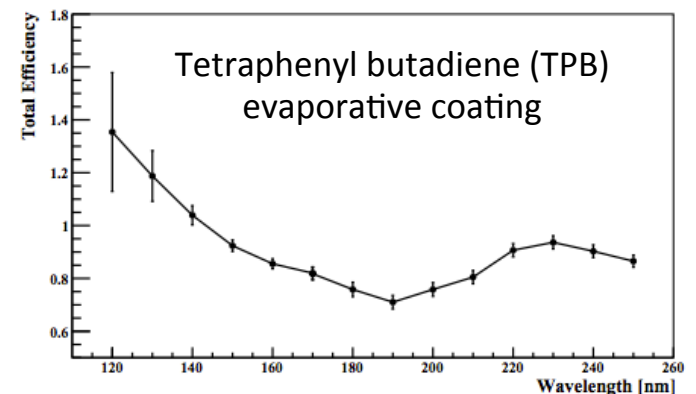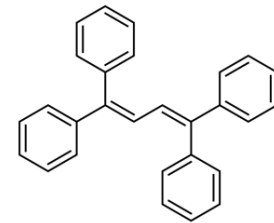
V. Gehman et al, NIM A 654, 116 (2011)

LAr Light Detection Motivation

- Provides interaction time (t_0) to reconstruct drift coordinate and correct track energy

- Trigger detector readout (especially for non-beam events)

- Cosmic background rejection

- Event reconstruction/particle ID

D. Whittington, IU

Cosmics during drift window

ν

TPC

LAr Light Detection Motivation

ELBNF Requirements

Key R&D Goal

- Provides interaction time (t_0) to reconstruct drift coordinate and correct track energy

- Trigger detector readout (especially for non-beam events)

Increase photo-detection coverage/efficiency

- Cosmic background rejection

- Event reconstruction/particle ID

LAr Light Detection Motivation

ELBNF Requirements

Key R&D Goal

- Provides interaction time (t_0) to reconstruct drift coordinate and correct track energy

- Trigger detector readout (especially for non-beam events)

Increase photo-detection coverage/efficiency

- Cosmic background rejection

Main SBN Requirement

Improve photo-detection position/timing resolution

- Event reconstruction/particle ID

LAr Light Detection Motivation

ELBNF Requirements

Key R&D Goal

- Provides interaction time (t_0) to reconstruct drift coordinate and correct track energy

- Trigger detector readout (especially for non-beam events)

Increase photo-detection coverage/efficiency

- Cosmic background rejection

Improve photo-detection position/timing resolution

Main SBN Requirement

- Event reconstruction/particle ID

Demonstrate techniques in a ν LArTPC

DM Experimental Techniques

Increase photo-detection coverage/efficiency

To maximize TPC active regions, ELBNF requires thin profile photodetectors that sit inside wrapped APAs

Cathode Plane Assemblies   Anode Plane Assemblies

14m

Field Cage

3.74m

22.4m   Foam Insulation

Concrete Liner

7 m

1.25 m

x4

SiPM (x3)

128 nm LAr scintillation light

430 nm shifted light (in bar)

TPB coated acrylic light guide
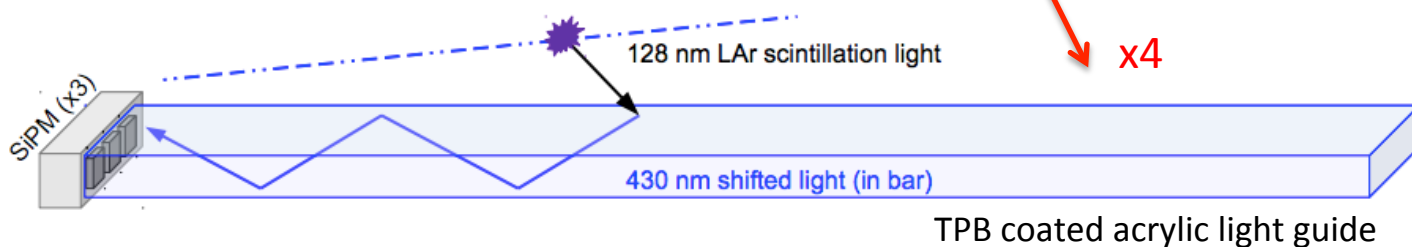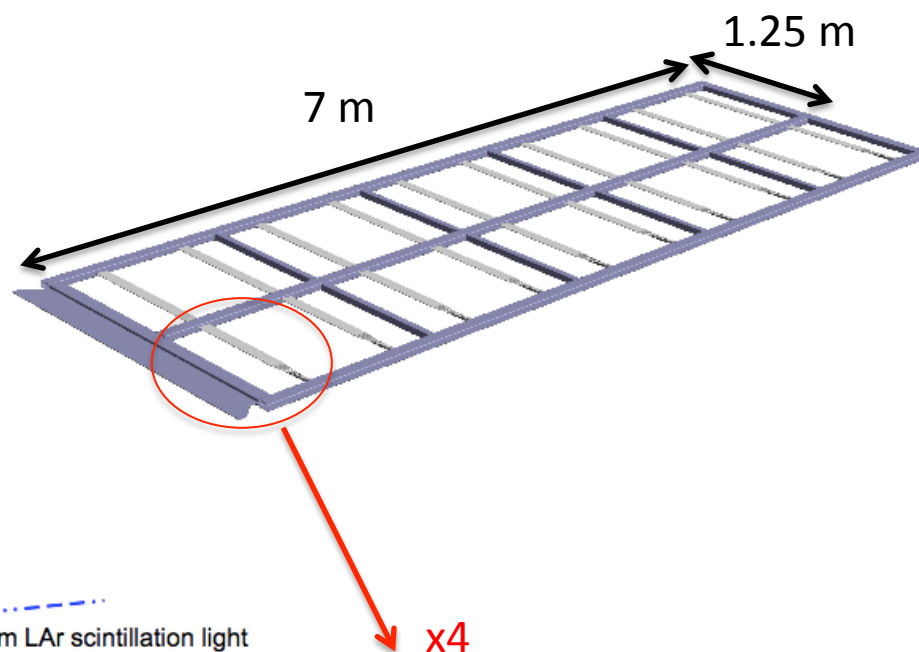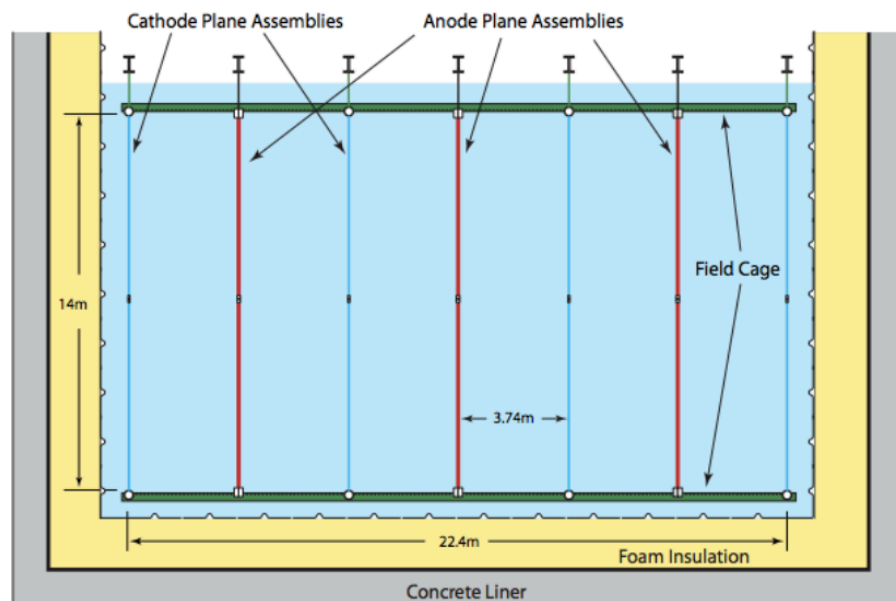
Increase photo-detection coverage/efficiency

R&D Needed To:

- Improve WLS conversion efficiency at surface
- Decrease propagation loses (e.g. arXiv:1410.6256)
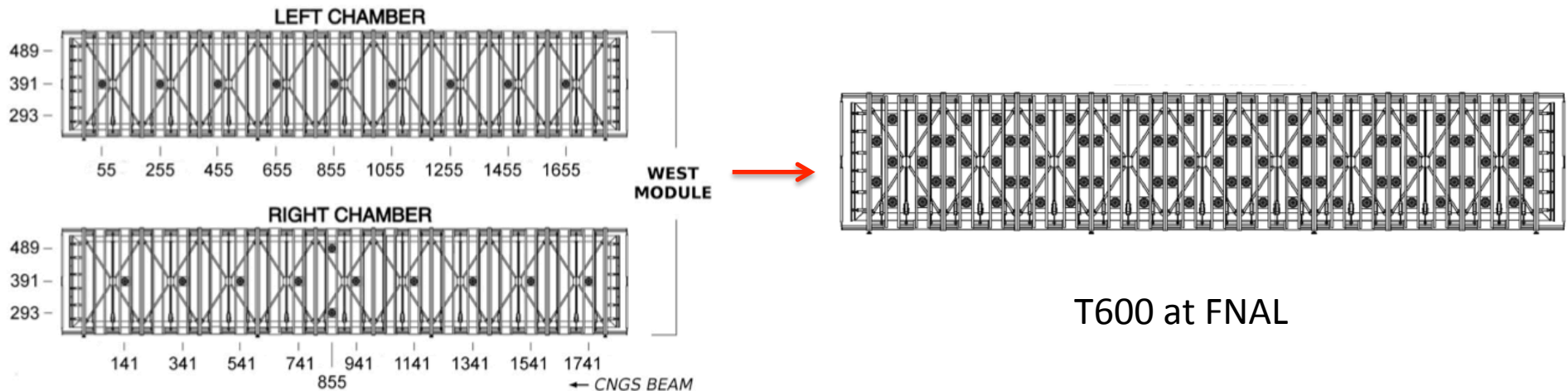- Improve bar response uniformity
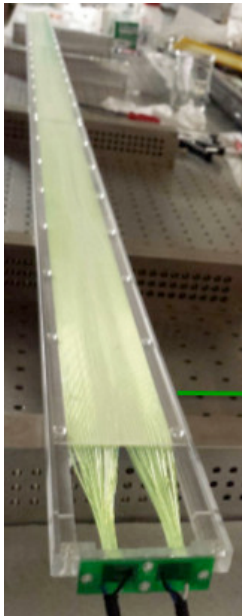
CSU

LSU

IU

Increase photo-detection coverage/efficiency

SBN experiments are not constrained by wrapped APAs (PMTs can be used) and can increase photo-detector coverage directly (due to their smaller size)
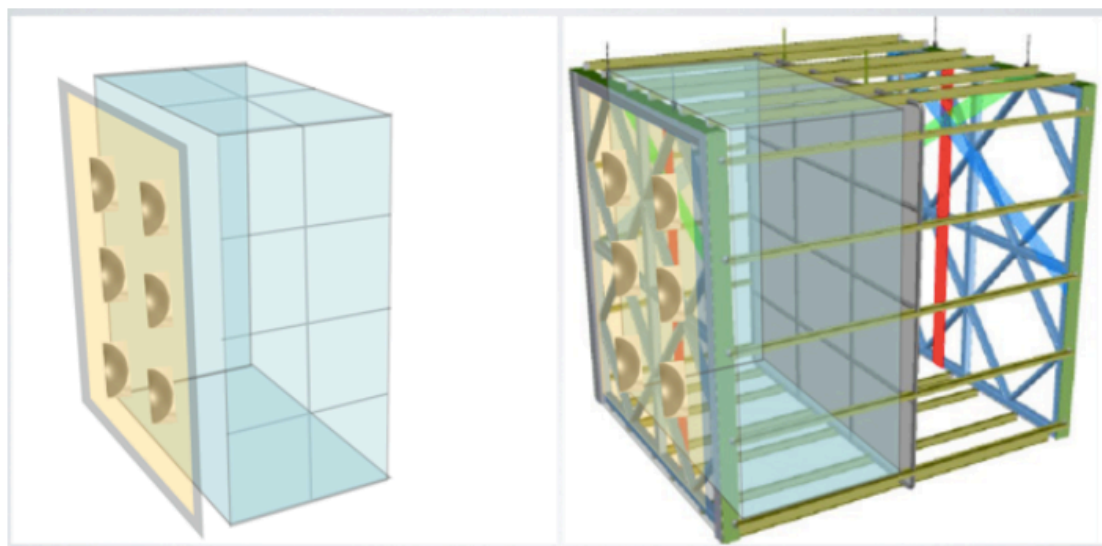

T600 at LNGS

T600 at FNAL

LAr1ND is considering a similar strategy with light guide bars or PMTs

Increase photo-detection coverage/efficiency

An alternative idea inspired by DM experiments is to line the TPC field cage with TPB-coated reflector foils


Conceptual design for LAr1ND

Reflections smooth out positional dependence of detected photons

Combining this with enhanced photo-detector coverage can dramatically increase the amount of light collected

Improve photo-detection position/timing resolution

SBN sensitivities require additional 95% cosmic rejection by
- Scintillation light/TPC track matching
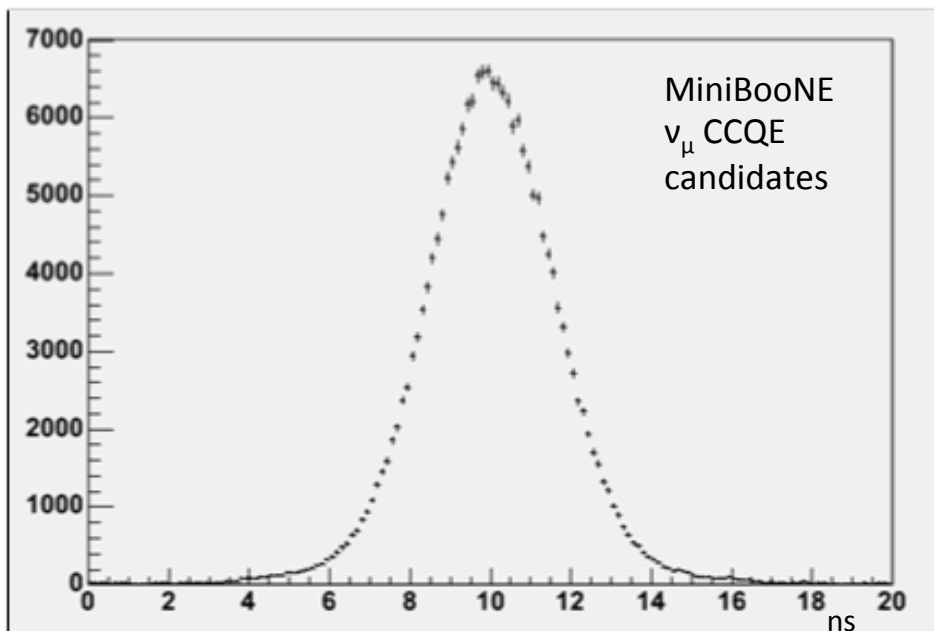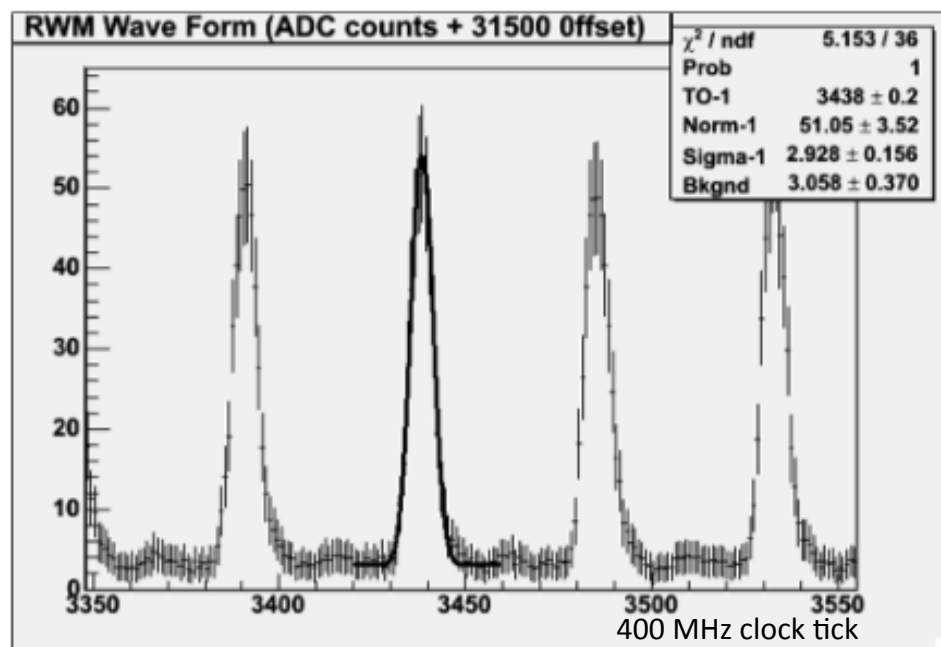- Resolving the RF structure of the Booster beam
- An external muon tracker

WINP 2015
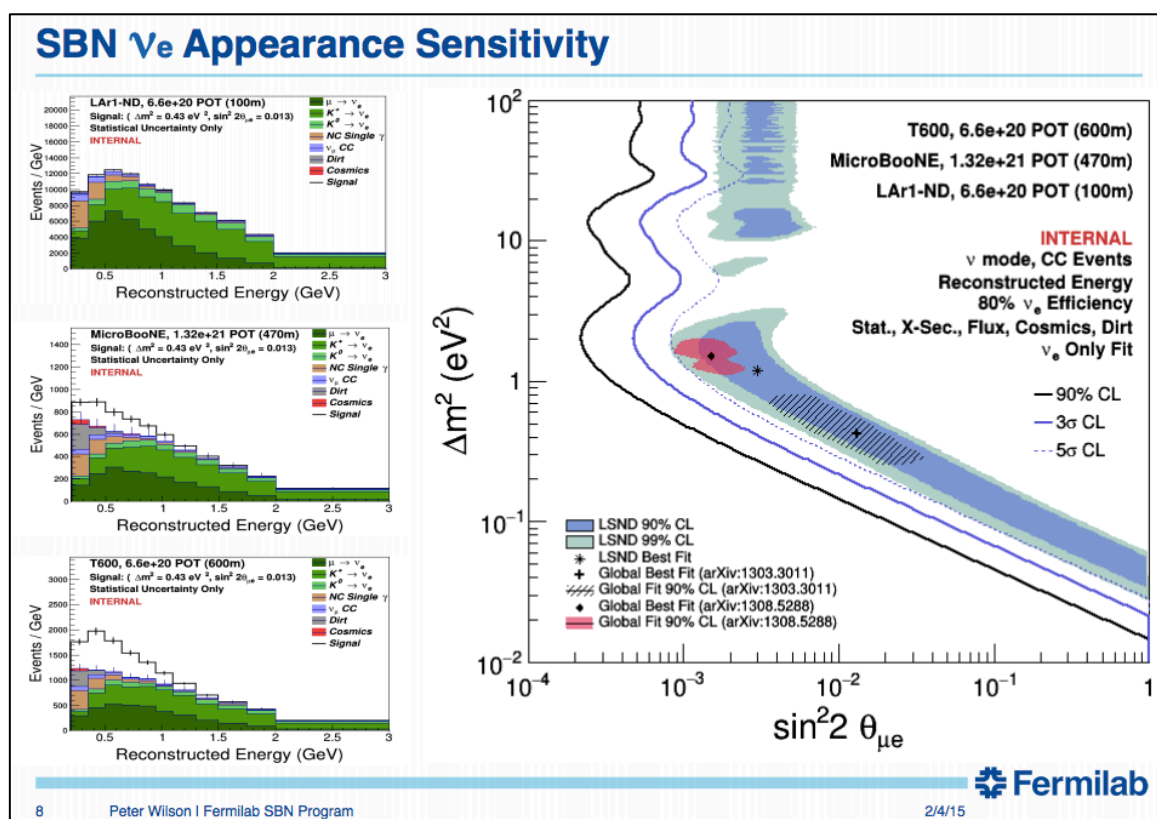
Improve photo-detection position/timing resolution

Using first photons, ultimate limit on timing resolution should be < 6ns

MiniBooNE can now resolve the RF structure of the Booster beam:
- Enhanced cosmic background rejection
- Can look for beam-related activity between RF buckets

RWM Wave Form (ADC counts + 31500 Offset)

χ^2 / ndf	5.153 / 36
Prob	1
TO-1	3438 ± 0.2
Norm-1	51.05 ± 3.52
Sigma-1	2.928 ± 0.156
Bkgnd	3.058 ± 0.370

400 MHz clock tick

MiniBooNE ν_μ CCQE candidates

ns

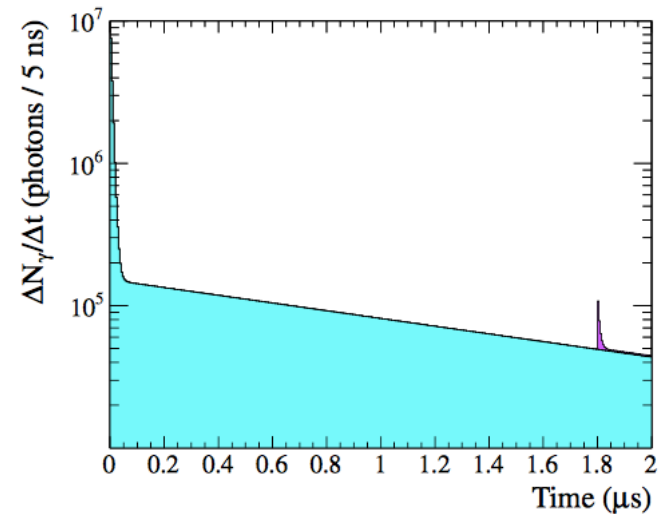→ Key capability of SBN program should be exploited

Event reconstruction/particle ID

Improve calorimetric energy reconstruction of few-GeV CC ν_e:
- Combining charge and light signals
- Correcting for missing secondary neutrino energy (Michel tagging)
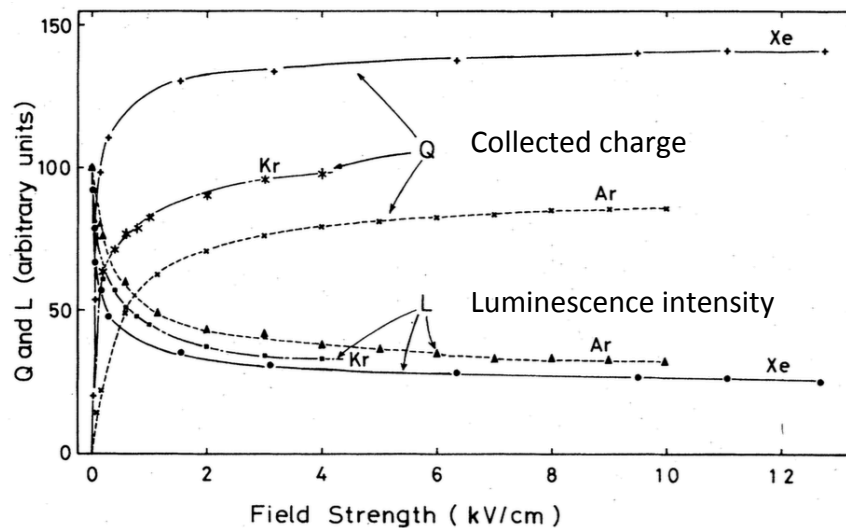
S. Kubota et al., Phys. Rev. B, 20, 8 (1979)

JINST 9 (2014) P10002

Statistically separate ν_μ events in a $\overline{\nu}_\mu$ beam (Michel tagging)

$\longrightarrow$ Both require detecting 10^{-3} of photons produced

More R&D is needed

- How far down can we push the thresholds for t_0 reconstruction and triggering in ELBNF?

- How does position/timing resolution depend on photo-detector granularity?
  - How well can light flashes be matched to TPC events?
  - How far down can we push the timing resolution?
  - Do reflector foils destroy position/timing resolution?

- How does light improve calorimetric energy resolution?

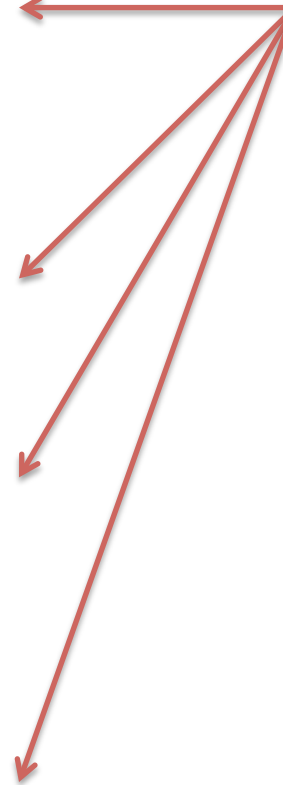- Can "wrong-sign" ν_μ be efficiently separated from a $\overline{\nu}_\mu$ beam?

LAr Scintillation light

- LAr is a bright scintillator: O(10,000) γ/MeV

- LAr scintillates in the VUV at 128 nm

- LAr is very transparent to its own light
  - Rayleigh scattering length: λ≈90 cm

- LAr light divided between two components
  - Fast component: τ≈6 ns
  - Slow component with τ≈1.5 us

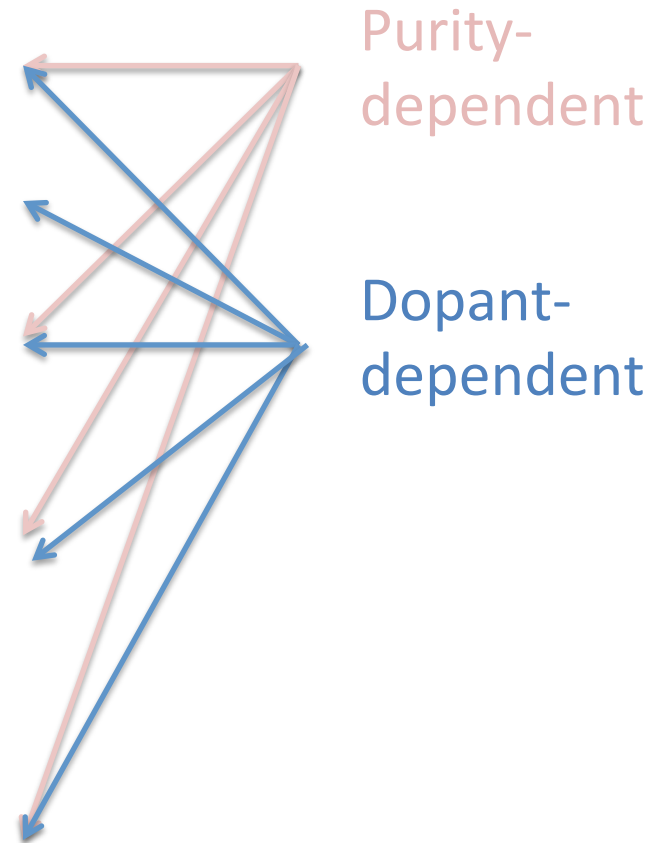- LAr scintillation light and charge anti-correlation

LAr Scintillation light

- LAr is a bright scintillator: O(10,000) γ/MeV

- LAr scintillates in the VUV at 128 nm

- LAr is very transparent to its own light
  - Rayleigh scattering length: λ≈90 cm

- LAr light divided between two components
  - Fast component: τ≈6 ns
  - Slow component with τ≈1.5 us

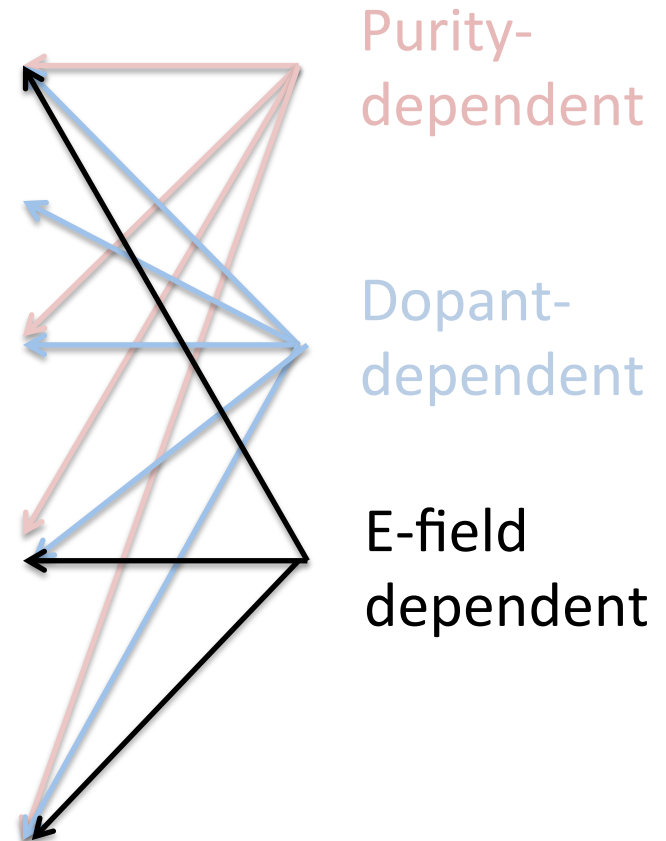- LAr scintillation light and charge anti-correlation

Purity-dependent

LAr Scintillation light

- LAr is a bright scintillator: O(10,000) γ/MeV

- LAr scintillates in the VUV at 128 nm

- LAr is very transparent to its own light
  - Rayleigh scattering length: λ≈90 cm

- LAr light divided between two components
  - Fast component: τ≈6 ns
  - Slow component with τ≈1.5 us

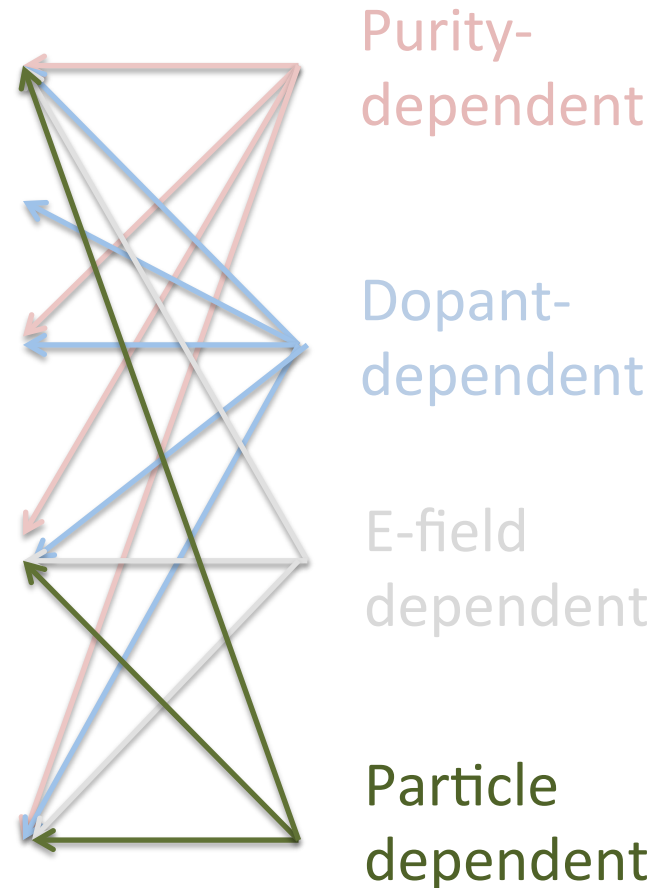- LAr scintillation light and charge anti-correlation

Purity-dependent

Dopant-dependent

LAr Scintillation light

- LAr is a bright scintillator: O(10,000) γ/MeV

- LAr scintillates in the VUV at 128 nm

- LAr is very transparent to its own light
  - Rayleigh scattering length: λ≈90 cm

- LAr light divided between two components
  - Fast component: τ≈6 ns
  - Slow component with τ≈1.5 us

- LAr scintillation light and charge anti-correlation

Purity-dependent

Dopant-dependent

E-field dependent

LAr Scintillation light

- LAr is a bright scintillator: O(10,000) γ/MeV

- LAr scintillates in the VUV at 128 nm

- LAr is very transparent to its own light
  - Rayleigh scattering length: λ≈90 cm

- LAr light divided between two components
  - Fast component: τ≈6 ns
  - Slow component with τ≈1.5 us

- LAr scintillation light and charge anti-correlation

Purity-dependent

Dopant-dependent

E-field dependent

Particle dependent

R&D Related to LAr Scintillation Light

- Purity
  - Nitrogen removal

- Dopants
  - TMG, Xenon, etc.

- Particle-ID
  - Ratio of fast/slow light

R&D Related to LAr Scintillation Light

- Purity
  - Nitrogen removal

Can we recover purity if N_2 is introduced?

- Dopants
  - TMG, Xenon, etc.

Should we shift late light to earlier times, longer wavelengths?

Should we convert some light back into charge?

- Particle-ID
  - Ratio of fast/slow light

Do DM particle-ID techniques work in neutrino beam events?

SiPM R&D Opportunities

- Are SiPMs robust against cryo-cycling?

- Should SiPMs be ganged together? How?

- What is the best signal cable to use?

- Can we make high density SiPM signal feedthroughs?

- Can we make SiPMs directly sensitive to 128 nm light?
  - These already exist for LXe

Conclusion

- LAr scintillation light provides key capabilities for future ν LArTPCs

- Exciting possibilities exist to extract even more physics information from the light

- More work needs to be done to translate physics requirements into detector requirements

- Further detector and cryo R&D are needed to develop robust and efficient ν LArTPC photo-detection systems

End.